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PRELIMINARY STUDY
of
WATERSHED MANAGEMENT AND WATER YIELDS
of the
UPPER GILA RIVER

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UPPER GILA RIVER

by

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Foreword

The management plan for the watershed lands of Southwestern streams must be directed toward several objectives. The effect of treatment measures on water yields is one of the important considerations in the development of the plan. This paper is a preliminary examination of this aspect of planning with respect to the upper Gila River.

Introductory Statement

The upper Gila watershed produces the water for 45,000 acres of irrigated land above Coolidge dam and for the 100,000-acre San Carlos project below. The return from these lands is extremely high because of their fertile soils and the favorable growing season. The value of each acre-foot of irrigation water is proportionally high, since the availability of water rather than of land limits project development. Any program of management for the upper Gila watershed, therefore, must have the maintenance of maximum delivery of irrigation water as one of its objectives. Since the upper Gila watershed is also a flood producing area, the control of floods, especially the frequent relatively small ones, is also of concern.

Soil erosion is an equally important upper Gila problem. Large areas of the watershed lands have been gullied and about 10,000 acres of the irrigated valleys have been completely lost. This destructive process continues to deplete the forage and agricultural productivity of the area and is affecting the regime of the river. Allied to the problem of erosion itself is that of reservoir sedimentation. Erosion products are accumulating in the San Carlos reservoir so rapidly that its effective operation may extend only about forty-five years. An equally serious effect of sedimentation is that it causes increasing exposure of stored water with consequent high evaporation losses.

Water conservation, flood control, erosion control and sedimentation reduction are generally recognized as interrelated objectives in the management of the upper Gila watershed. For example, as early as 1917 Olmsted in a report to the Secretary of the Interior (6)* recommended a program which, while

*Numbers in parenthesis refer to the correspondingly numbered title in the appended bibliography.

designed primarily for flood control, would also control erosion of the watershed. In 1934 Senator Carl Hayden proposed the creation of a federal upper Gila conservancy to implement a multiple purpose program embracing all four objectives. The upper Gila project of the Soil Conservation Service, although established primarily for erosion control includes also sedimentation reduction and water conservation in its program objectives. While these four objectives clearly are interrelated, careful planning is necessary to assure fulfillment of their complex requirements through a comprehensive management program.

Erosion control and runoff regulation are accomplished, in most cases concurrently, by various management and treatment measures. One effect of these operations is to increase the infiltration of precipitation and surface runoff. Significant effect from this on the delivery of winter precipitation is not anticipated since ground flow is a major source of winter discharge. A considerable portion of the summer yield, however, is commonly considered to be secured from such surface runoff as reaches the Gila River channel. The effect of increased infiltration of summer precipitation on available irrigation supplies is, therefore, a problem of some importance in the design of the management program.

Cooperrider and Sykes (1) state that on the adjacent upper Salt River watershed most of the summer precipitation is dissipated through evaporation before it reaches the reservoir. They point out that, on many parts of the watershed, increased infiltration of summer precipitation for the purpose of reducing soil erosion would not decrease irrigation supplies since most of the water put in the ground would otherwise have been lost through evaporation.

Although the results of the Salt River investigations by and large are applicable to the mountainous portions of the upper Gila, they cannot be applied to the entire upper Gila watershed since its physiography and hydrologic behavior are not entirely congruent with those of the upper Salt. Cooperrider and Sykes' analysis shows that only about 6% of the water reaching the Roosevelt reservoir is derived from summer

precipitation. The upper Salt River, moreover, is never entirely dry; its summer base flow from ground water sources delivers about 11% of the average annual flow. The upper Gila, however, in many years is entirely dry immediately above the reservoir for two months, and during that period its base flow through the upper valleys dwindles to only a few second feet. Other dissimilarities arise from the systems of irrigation use of the two rivers. All of the water of the upper Salt is caught in Roosevelt reservoir before delivery to any irrigation project, and, therefore, changes in the timing of delivery are relatively unimportant. In the upper Gila, however, there is considerable use of water by direct diversion above any reservoir. Adjudication of the rights of the upper users with reference to those of the reservoir users provides limitations upon diversion. The effect of these legal limitations might vary according to the manner of delivery of increments to streamflow. This latter point is mentioned to indicate that certain complicated legal regulations in their relation to the delivery of summer precipitation waters must be considered in the development of the treatment program.

Relatively little information pertaining to the relation of the various watershed treatments to the conservation of summer rainfall is specifically applicable to the upper Gila. Development of such information through controlled experiments on small areas is a lengthy task; the relatively slow response of vegetation in the upper Gila country, and the erratic distribution of summer precipitation necessitates long-period investigations to assure inclusion of sufficient observations. While such experimental work is essential for the solution of several important problems, the immediate need for information to guide program planning suggests exploration of other approaches.

The investigation was undertaken originally in order to determine to what extent river hydrographs and existing precipitation records may yield information pertinent to the development of a watershed treatment program. When preliminary work confirmed the writers' belief that this approach is a favorable one, the investigation was extended to include an analysis of unrefined data in order 1) to indicate the type of information which may be developed and, 2) to set more specifically

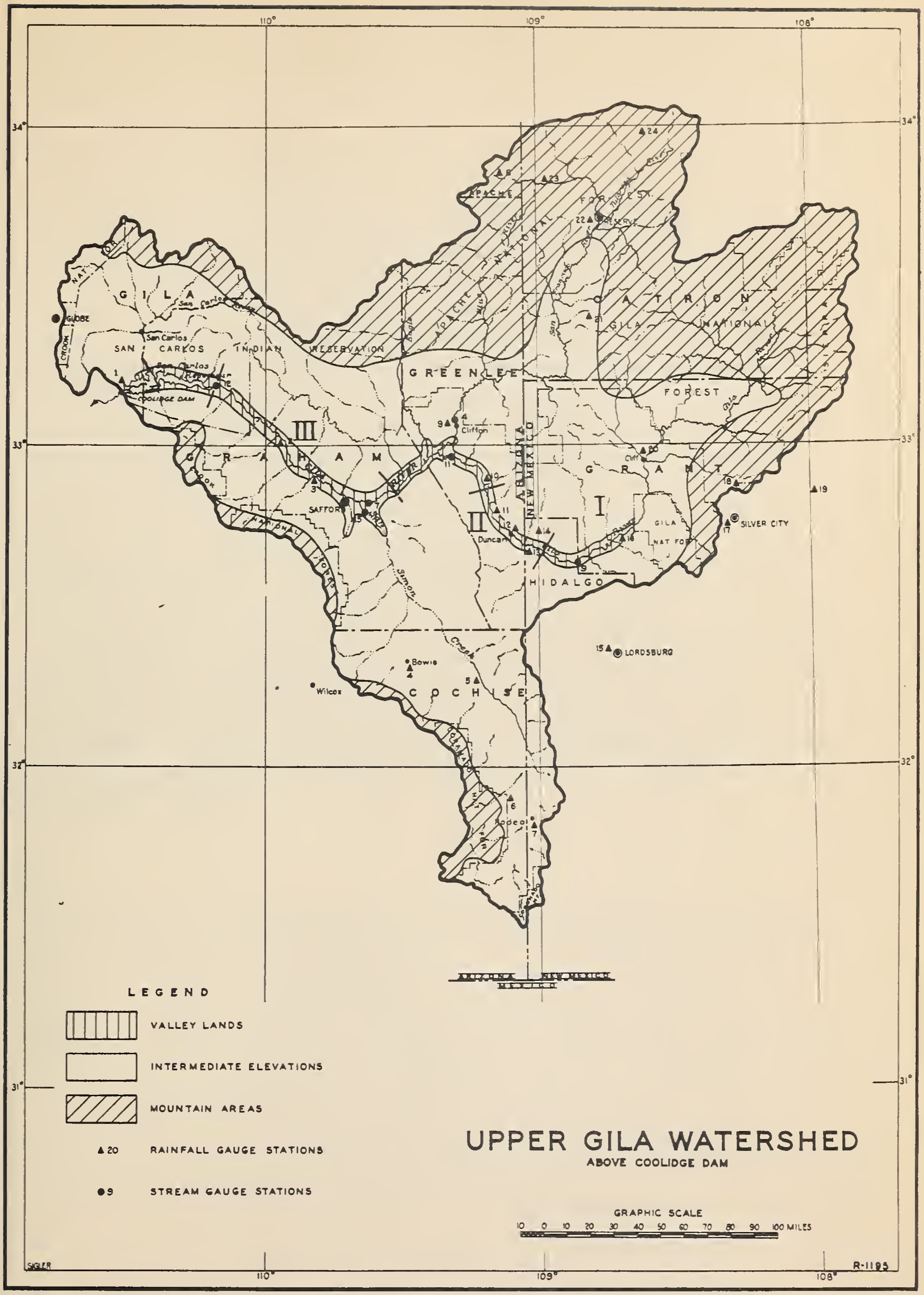
the problems which should be included in further studies.

Preliminary presentations of this material led the authors to lay aside their reluctance to discuss the implications of preliminary findings. A further purpose of this paper, therefore, is to indicate the probable effect of certain treatment measures on the water yield of summer precipitation in the upper Gila watershed.

Description of the watershed.

Figure 1 illustrates the significant physiographic and topographic features of the upper Gila watershed. It is an area of eight million acres and like most other southwestern watersheds presents physiographic extremes. Elevations range from about 2,000 feet at the dam to about 11,000 feet in the Mogollon and Blue ranges. The climate of the area as a whole is distinctly semi-arid, but the high mountains contain limited areas of Canadian-type vegetation because of the much higher precipitation and the relatively temperate climate.

In general, three physiographic zones may be recognized: 1) the valley proper extending along the main river from the reservoir to about Cliff, New Mexico; 2) the intermediate lands extending northward and southward from the valley to the foot of the mountain masses, and 3) the mountains which form the perimeter of the watershed. The valley is approximately 135 miles long and varies in width from 1 to 15 miles. Summer temperatures of 100° are equalled and exceeded, evaporation rates are in excess of fifty inches per year, and precipitation, especially in the summer time, is irregularly distributed. Favorable locations in the vicinity of Safford, Duncan, and Red Rock are intensively cultivated. The slopes, especially to the south, are extensive including over five million acres. They are intermingled grass and brush lands varying in elevation from 2500 feet to 5000 feet. Especially in the lower elevations, they are semi-arid with high evaporation rates and with a summer rainfall which is commonly of relatively high intensity and short duration. The mountainous area, with the exception of the Graham and Chiricahua Mountains along the south, lies north and east of the river. Woodland and timber types interspersed with grass parks cover the mountains; summer as well as winter precipitation far exceeds


UPPER GILA WATERSHED
ABOVE COOLIDGE DAM
LEGEND
VALLEY LANDS
INTERMEDIATE ELEVATIONS
MOUNTAIN AREAS
RAINFALL GAUGE STATIONS
STREAM GAUGE STATIONS
GRAPHIC SCALE
10 0 10 20 30 40 50 60 70 80 90 100 MILES
GILA
SAN CARLOS INDIAN RESERVATION
GREENLEE
GRAHAM
COCHISE
HIDALGO
GRANT
CATRON
GILA NATIONAL FOREST
APACHE NATIONAL FOREST
ARIZONA
NEW MEXICO
MEXICO
GLOBE
San Carlos
COOLIDGE DAM
Clifton
SAFFORD
Duncan
SILVER CITY
LORDSBURG
Bowie
Wilcox
Rodeo
110°
109°
108°
34°
33°
32°
31°
R-1195

that of the lower elevations.

For the purposes of this investigation the river itself has been divided into three main reaches: 1) from the headwaters to the head of the Duncan Valley; 2) the Duncan Valley itself; 3) from the head of the Safford Valley to the head of San Carlos reservoir; the short twenty-mile stretch between the mouth of the Duncan Valley and the head of the Safford Valley is disregarded. These divisions were made primarily so as to permit ready analysis of rainfall-streamflow relationships. While they are determined by the location of gauges, they also reflect certain real divisions. Since relatively little water is diverted for irrigation above the head of the Duncan Valley, the 6,000-acre project there may be considered as the farthest upstream irrigation area. The Safford Valley differs from the Duncan Calley because the Gila River below the mouth of the Duncan Valley receives important contributions of water and of silt from various tributaries; in the Duncan Valley, no important water-contributing tributaries enter the Gila, although the Railroad wash and other side drainages are important sources of silt. Figure 1 shows the three reaches and the location of the streamflow and rain gauging stations whose records are used in this study.

Procedure.

The procedure followed in this investigation is directed toward 1) the selection of sections of the summer hydrographs in which the effect of precipitation may be observed and, 2) the analysis of those hydrographs together with precipitation and diversion records for the purpose of ascertaining the amount of irrigation water obtained from summer rains. The method, in brief, is to trace downstream through a given reach of the river a rise developing from precipitation and to determine the proportions of the rise which were diverted in the reach, delivered to the mouth of the reach, and lost in transit. The analysis of each incident is considered a separate observation and is reported below.

The result of the analysis is expressed as "net loss" or "net gain." This is obtained by subtracting from the inflow increment at the head of the reach the sum of the outflow incre-

ment and the diversion increment; positive remainders indicate the disappearance of some of the inflow and are therefore "net loss"; negative remainders indicate the reverse and are "net gain".

Gains and losses were determined for the streamflow increments and diversion increments which were due to precipitation. These increments are the mass between the actual hydrograph and the trend curve; i. e. between actual runoff and the "recession curve" in the case of streamflow, and between actual diversions and the "irrigation trend curve" in the case of diversions. The recession curves are graphic descriptions of the way in which streamflow would decrease from the spring high through the summer low stages were it not for the increments from the summer precipitation; the irrigation trend curves are graphic descriptions of the way in which diversions would decrease through the summer along with the depletion of the river were it not for the increments to the river from summer precipitation. Curves for the head and the mouth of each reach and for the diversions in the reach were constructed for each year by fitting together the arcs of the appropriate daily hydrographs during periods when no increment was received from summer precipitation; the curves for each of the two years here investigated were so similar that their combination into a single relatively smooth curve by visual means was possible. Daily hydrographs of the period March 15 to October 15 for each of the points of reference are the basis of these trend curves. It is not possible to reproduce the complete daily hydrographs in this paper and only the individual observations are figured. The complete irrigation trend and recession curves for the summer season are, however, shown in figs. 2 and 3. Since the San Simon River flows only intermittently no recession curve is plotted for it and hence, as will be evident later, a somewhat different analysis is made of its runoff. Appended as notes 1 and 2 are sample calculations to illustrate the application of this procedure in the construction of the two types of incidents reported.

Precipitation, segregated as rain on the watershed above the head of each reach and on the watershed directly tributary to the reach itself, was plotted upon the general hydrograph in order to control the construction of the trend curves and to guide the selection of periods for analysis. No single pre-

cipitation station can be used as an index for any of the areal units delineated because of the localized character of summer rain. The measure used, therefore, is the mean of the records at all gauges in a given area, including in the calculation of the mean those stations at which no precipitation was recorded. This calculation is taken as an index of both the amount of rain and also of its areal extent.

The hydrographs of streamflow and of diversions were plotted from the daily mean flow as reported in the annual reports of the Gila Water Commissioner (2,3). Precipitation data were secured for 15 standard stations operated by the U. S. Weather Bureau, and for 6 reconnaissance type stations operated by the Soil Conservation Service. The location of the stations is shown in fig. 1.

Various deficiencies are recognized in these data for rainfall-runoff investigations. First might be mentioned those due to the manner of record making; they are comprehensively discussed by Hoyt and others (5). Another important deficiency of the data is that the actual summer precipitation of many portions of the watershed is not truly represented by any group of rain gauges. Since summer rainfall is extremely localized, it may occur with no showing on any gauge, while a record of intense rainfall at even several gauges does not always truly indicate a general condition. Although the existence of these deficiencies necessitates caution in the interpretation of data, the writers believe that the data used are fairly representative of the conditions obtaining during the two years which are the period of this investigation. The constant field observations made by one of the authors in the upper Gila country during that period, furthermore, have provided a valuable control upon interpretation of the records.

Exact streamflow information concerning diversions in the Safford and Duncan valleys exists only for years 1936 and 1937. This short period is not, however, as disadvantageous as might be supposed. Table 1 contains an analysis of the mean monthly discharges of the upper Gila River at the various stations for the period of record. Examination of this tabulation demonstrates that 1936 and 1937 are fairly representative of the modal behavior of the river, 1936 being slightly under

modal discharge and 1937 being slightly greater than modal discharge for most months. It is recognized, of course, that the results of this study are not necessarily applicable to years either of extremely high discharge or of extremely low discharge.

As this study is an exploratory one primarily intended to test the usefulness of hydrograph analysis to watershed management planning, only a relatively meager series of observations and very crude data have been used. Although, so far as the writers are aware, there has been no previous use of exactly the same method of analysis that is employed in this study, the principles upon which it is based are those published by Horton, Hoyt, and others (4,5). The tentative conclusions suggested in a later section are offered as indicative of the possibilities of the method rather than as facts established by the evidence. The writers believe that any rejection of those tentative conclusions would be because of the meager data used rather than because of the method of analysis. As will be shown later, however, even with crude data, the method appears sufficiently sensitive to detect hydrologic phenomena of quite small magnitude.

Observations.

Thirteen incidents were examined and are reported here in chronological order as individual observations. Several of those incidents are so similar in their important characters that they are virtually replications comparable with those in controlled experiments.

The first eleven observations here reported are for the Duncan reach, they are numbered 1 to 11 in the accompanying table, and are figured in figs. 4 to 14. The following remarks supplement tabular and graphic data:

#1 (fig. 4) Heavy downfall of short duration in the watershed above the Duncan reach resulted in a net loss of 104 second foot days, most of which developed at the rate of 50 second foot days per day.

Table I

Monthly discharge as percentage of mean monthly discharge for years of record

Gauging Station		Fuller's Ranch	Gila at Clifton Bridge	San Francisco at Clifton	Gila below Bonita Creek	San Simon Near Solomonsville	Gila at Calva
	1936	12*	16	17	23	4	42
Years of record	1937	13*	17	18	24	5	43
January	1936	100	33	44	21	23	28
% of mean discharge	1937	111	36	57	28	9	35
February	1936	115	67	98	102	3	191
% of mean discharge	1937	39	21	30	258	0	254
March	1936	50	33	37	52	0	43
% of mean discharge	1937	22	184	122	198	0	201
April	1936	55	33	67	49	0	27
% of mean discharge	1937	149	126	109	103	0	80
May	1936	51	28	59	48	9	16
% of mean discharge	1937	113	108	97	99	0	67
June	1936	50	48	55	60	400	5
% of mean discharge	1937	127	121	79	103	329	34
July	1936	34	24	35	32	147	11
% of mean discharge	1937	39	21	36	30	39	4
August	1936	13	31	39	29	56	19
% of mean discharge	1937	23	23	27	19	10	4
September	1936	87	74	88	79	177	80
% of mean discharge	1937	81	97	72	83	43	41
October	1936	50	21	24	33	0	10
% of mean discharge	1937	53	31	28	40	29	28
November	1936	85	69	87	83	0	56
% of mean discharge	1937	67	52	54	56	0	35
December	1936	99	33	37	38	18	25
% of mean discharge	1937	87	33	32	33	141	27
Total	1936	59	39	54	50	73	52
% of mean discharge	1937	136	93	101	98	18	86

*Does not include high waters in years 1914-1917

#2 (fig. 5) Rain both above the reach and within it contributed to the rise. Of the net gain of 148 second foot days, 156 may be attributable to downfall within the reach itself. The loss of 8 second foot days thus calculated is not a significant quantity, and, therefore, this incident is truly a contribution to the irrigation supply.

#3 (fig. 6) Well distributed rains on the watershed above the head of the reach produced a river rise which, though of considerable amount, was of such character as to allow almost its complete diversion. Heavy rains in the reach itself although producing large rises apparently did not increase irrigation diversion.

#4 (fig. 7) is in effect a replication of #3.

#5 (fig. 8) This observation is for an incident during which diversions decreased coincident with downfall. That decrease may have been occasioned by the decreased demand for irrigation due to rainfall, or by inability to divert due to destruction of the dam by the rise. The important aspect of this incident is that in spite of substantial rains within the reach itself, some channel losses occurred during the movement of the original rise through the reach, as is shown by the low net gain figure.

#6 (fig. 9) is similar to #5. Although the ratio of the downfall within the reach to that above the reach is greater for this incident than is that for the preceding incident, the channel loss (net loss) remains proportionally as large.

#7 (fig. 10) is reported as illustrative of the fall type of rainfall-streamflow relationship. The hydrograph suggests that a considerable portion of the increment was delivered as ground flow.

#8 (fig. 11) In this incident the inflow rise from rains above the reach for the first few days developed a net loss due to channel losses in spite of rains within the reach. Continuing downfall in the upper area, however, resulted in considerable ground water delivery as is evidenced by the shape of the hydrograph; this effected a total net gain for the entire period.

Table II. - Data for observations, Duncan Reach

Obs. No.	Fig. No.	Date	Rainfall		Increments in sec. foot days			Net loss or gain (+ =loss (- =gain)
			Above the reach	In the reach	Inflow	Out-flow	Diver-sions	
1	4	June 5-19, 1936	Heavy, short duration	None	258	85	69	+104
2	5	July 8-22, 1936	Moderate, long duration	Heavy, short duration	313	144	110	-148*
3	6	Aug. 17-25, 1936	Moderate, well distributed	Heavy, short duration	221	333	193	-305
4	7	Aug. 26 - Sept. 1	Moderate, short duration	Heavy, short duration	492	1185	278	+971
5	8	Sept. 10-19, 1936	Heavy, short duration	Moderate, long duration	1548	1501	None	-47
6	9	Sept. 19-25, 1936	Heavy, short duration	Light	584	617	None	+33
7	10	Sept. 25-Oct. 7	Heavy, short duration	Heavy, long duration	342	289	None	+53
8	11	June 24-July 20, 1937	Heavy, long duration	Light, short duration	1774	844	581	+349
9	12	Aug. 5-Aug. 9, 1937	Light, short duration	Heavy, short duration	None	195	None	
10	13	Aug. 15-Sept. 1, 1937	Heavy, short duration	Heavy, short duration	1014	1353	213	-552
11	14	Sept. 5-20, 1937	Moderate, long duration	Heavy, short duration	1748	2689	209	-1250

*When adjusted, net loss 8 sec. ft.

#9 (fig. 12) This observation is an incident of almost exclusively rainfall within the reach proper. No increase in diversions are apparent and, furthermore, as was discovered from the Solomonville gauge record, the rise was dissipated below the reach by about 40 second foot days in twenty miles.

#10 (fig. 13) An inflow rise due to rains above the reach is depleted only very slightly by diversion. Outflow increment is almost the same as is inflow increment, suggesting that the yield of the relatively heavy downfall within the reach proper was only enough to compensate for channel losses.

#11 (fig. 14) is similar to #10.

Two incidents of Safford reach precipitation-streamflow relationship are presented as Observations 12 and 13. A number of other incidents were also examined and they displayed similar streamflow behavior; however, because of their complicated nature, their data and analysis are not included in this paper, due to its limited scope. In addition, some of the rises developing in the Duncan reach were traced through the Safford reach. Almost invariably their volume was dissipated as channel losses with negligible or no contribution to the irrigation supply.

#12 (fig. 15) During the period of this incident, heavy precipitation on the San Simon watershed produced a flow of 2000 second-foot days which joined a relatively low flow of the Gila River proper. Only minor increments to the river were received below the confluence. There was a relatively negligible increase in diversions within the reach, and only a relatively small increase in delivery to the San Carlos reservoir. Of the 2465 second-foot days discharge increment at Solomonsville, 1207 second-foot days were lost in transit through the reach. This loss occurred during six days of flow, or at the average rate of 200 second-foot days per day.

#13 (fig. 16) This incident differs from the preceding one in that the Gila received fairly large inflow increments from tributaries entering the reach below Solomonsville. In the absence of actual gauge records, that statement is supported

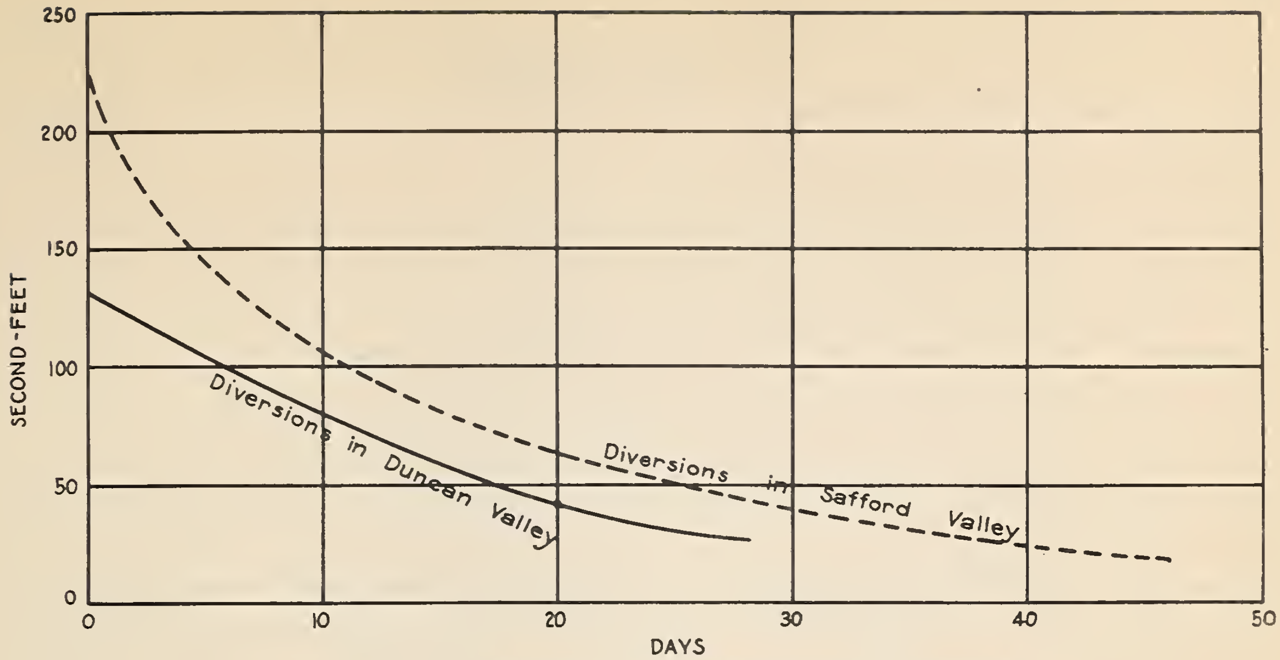


FIG. 2 UPPER GILA IRRIGATION TRENDS

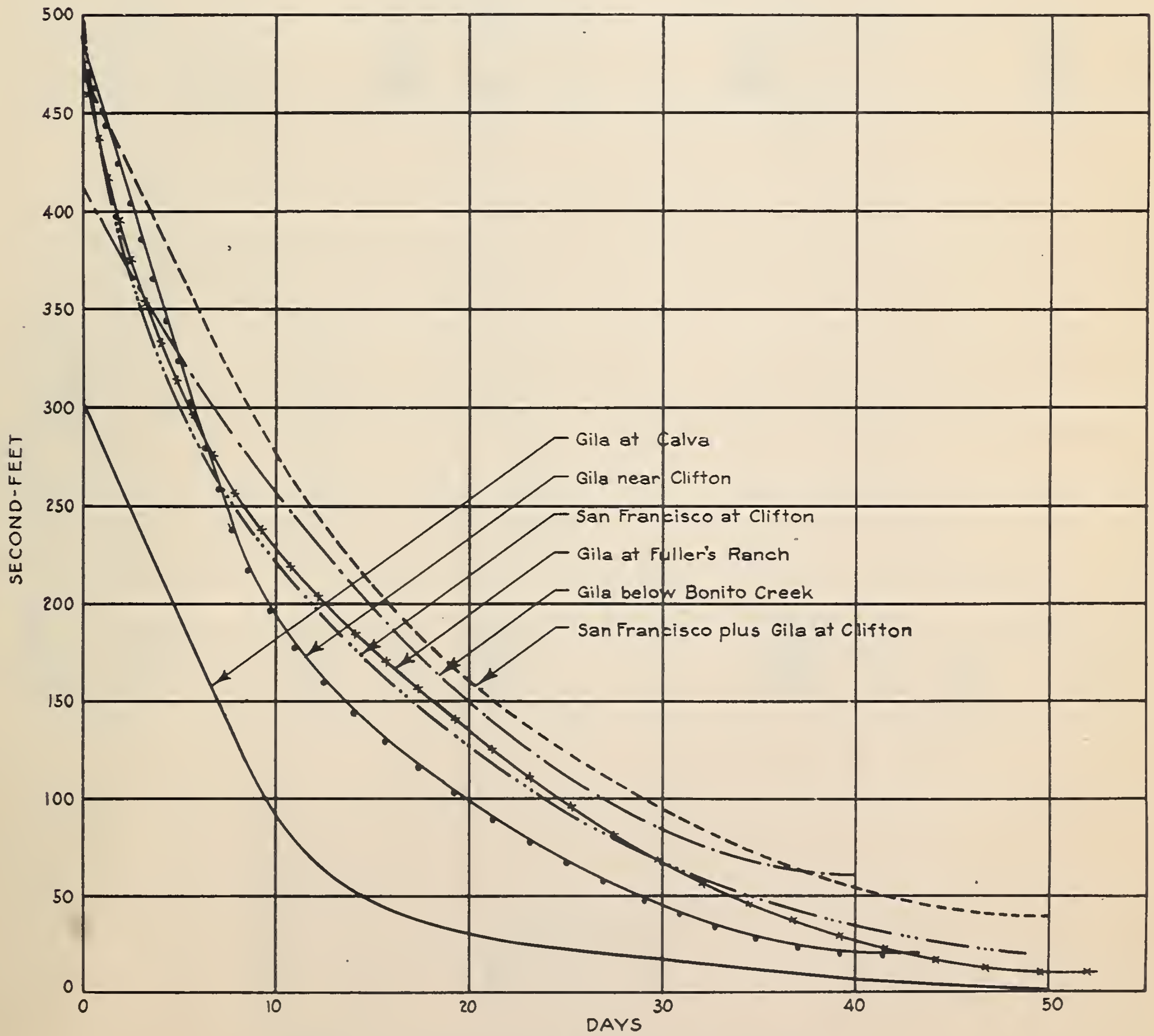


FIG. 3 UPPER GILA RECESSION CURVES

DUNCAN REACH

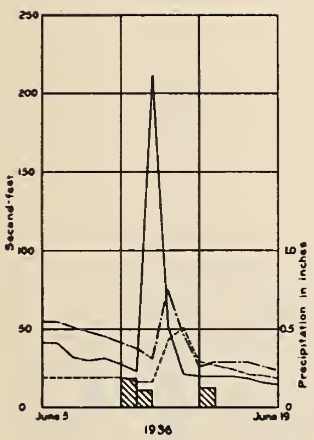


FIG. 4

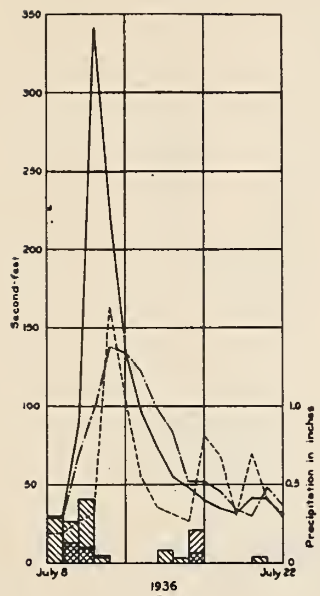


FIG. 5

FIG. 6

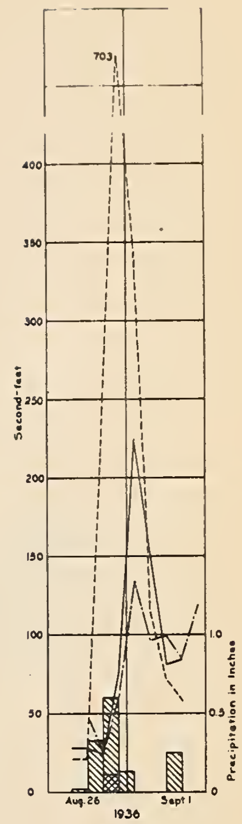


FIG. 7

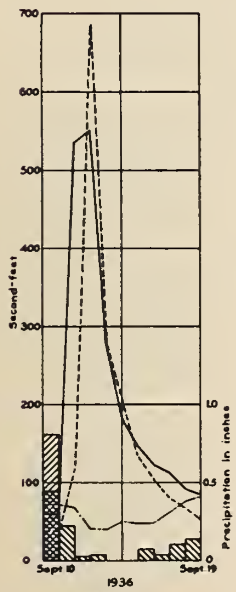


FIG. 8

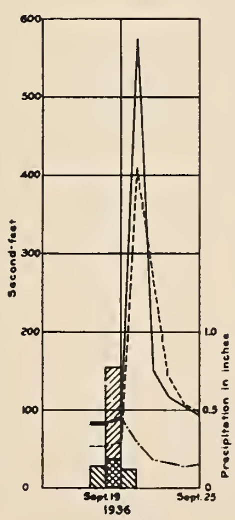


FIG. 9

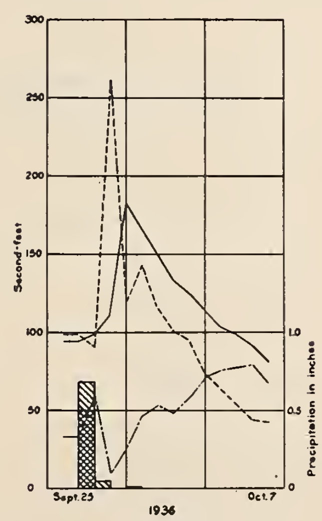


FIG. 10

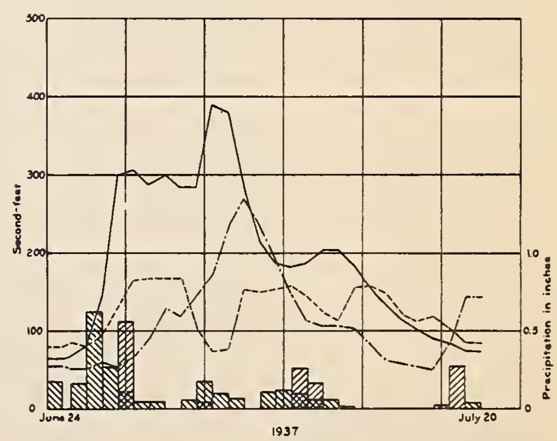


FIG. 11

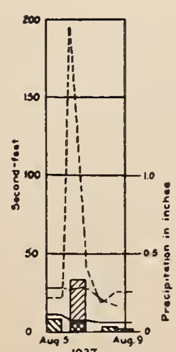


FIG. 12

- LEGEND -

Gila at Fuller's Ranch

Diversions in Duncan Valley

Gila near Clifton

Precipitation above Duncan

Precipitation near Duncan

DUNCAN REACH

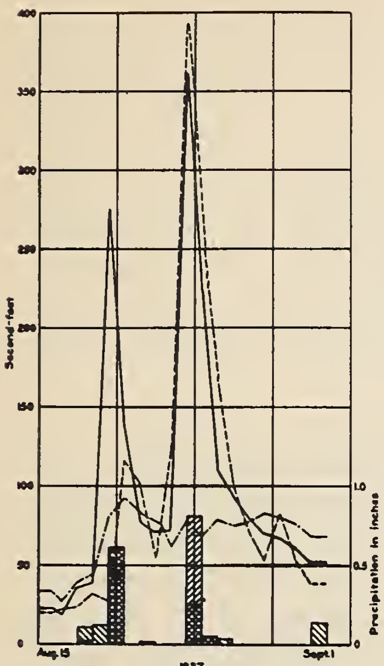


FIG. 13

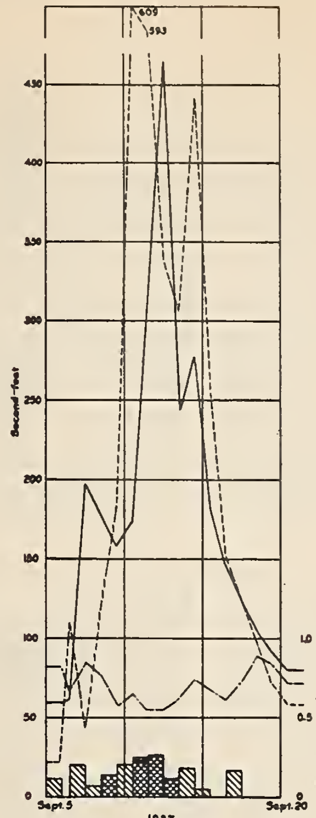


FIG. 14

- LEGEND -
Gila at Fuller's Ranch
Diversions in Duncan Valley
Gila near Clifton

Precipitation above Duncan
Precipitation near Duncan

SAFFORD REACH

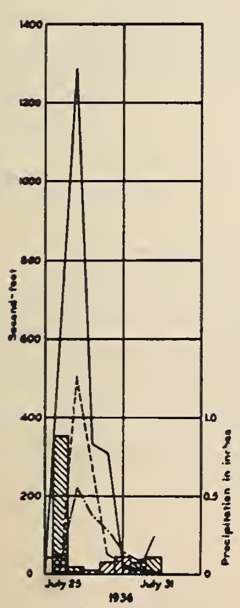


FIG. 15

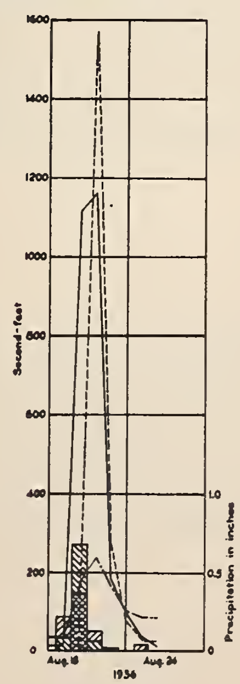


FIG. 16

- LEGEND -
Diversions above San Simon Creek deducted from Gila below Benito plus San Simon Creek
Diversions below San Simon
Gila at Calva

Precipitation for upper gauges
Precipitation for lower gauges

by the following evidence: The river rise at Solomonsville began on August 20, and the daily mean inflow at Calva increased from 0 to 1570 second-foot days on the same day. Since at least 24 hours are required for transit from Solomonsville to Calva, the latter rise apparently must have been derived from increased inflow below Solomonsville. If this reasoning is correct, the result of the inflow increment at the head of the reach was a net loss of at least 346 second-foot days and probably as great as that reported in #12. Further study of this incident, however, is needed.

A minor point of interest is suggested by the shape of the recession curves (fig. 3). It will be noted that at their lower end they flatten out above the zero discharge point. This indicates that even without the increment from summer precipitation a minimum base surface flow of the river is maintained from ground water sources. This conclusion, of course, does not apply to the reach in the vicinity of Calva, where, as was previously mentioned, dry channel conditions commonly prevail for as long as sixty days. Another point which is demonstrated by these curves is that the upper irrigated valleys are, in effect, water spreading areas. It will be noted that in the case of the Duncan Valley for example, on many days outflow at the mouth of the valley exceeds inflow at the head in spite of diversion in the reach. The explanation is that return flow from irrigation accounts for the difference and this indicates that irrigation functions partially as a regulator of base flow. These two points are in accord with expectation; their significance is that they show that even crude data can be sensitive indicators of hydrologic phenomena of small magnitude.

Discussion.

In the earlier paragraphs of this paper, watershed management planning was shown to require consideration of erosion control and runoff retardation in relation to irrigation supplies to either the San Carlos reservoir or to projects above it. This discussion is directed primarily to relating the rainfall-streamflow analysis to that problem.

Table III. - Data for observations, Safford Reach

Obs. No.	Fig. No.	Date	Rainfall		Increments in sec. foot days				Net Loss or gain (+ = loss) (- = gain)
			On San Simon Watershed	On Gila below mouth of San Simon	Gila above mouth of San Simon	San Simon	Gila Outflow At Calva	Diversions	
12	15	July 25-31	Heavy, short duration	Light, long duration	400	2065	870	388	+1207
13	16	Aug. 18-24	Moderate, short duration	Moderate, long duration	330	1957	2655*	645	+348**

*Largely from tributaries entering the reach below the mouth of the San Simon.

**Adjusted to compensate for inflow from tributaries below the San Simon, see accompanying notes.

Study of the limited number of preliminary observations leads to the following tentative conclusions regarding summer conditions:

1) Certain summer river rises contribute significantly to the supply of irrigation water, while other rises do not.

2) The rises which do contribute to the irrigation supply are derived from relatively general or continuing rains, principally in the high and intermediate elevations; the river rises which do not contribute materially to the irrigation supply are derived from rains falling in the river valley and on watersheds like the San Simon.

3) A significant portion of the streamflow increments which contribute to the irrigation supply is delivered to the river as ground flow.

The first two conclusions are derived from examination of observations 2, 3, 4, 8, 10 and 11 in comparison with observations 1, 5, 6, and 9. In the former group, general or continuing rains produced comparatively enduring rises from which either large diversions were made in the reach or large deliveries were made downstream. In the latter group, the rises derived from rainfall upon only the lower elevations were of short duration and neither significantly augmented diversions within the reach nor delivery downstream; their volume was largely dissipated in channel losses. Observations 12 and 13 strongly indicate the low value of rainfall on areas like the San Simon.

In this comparison, the important distinction from the point of view of water use is not the volume of the rise but its duration; the rises which quickly approach the recession curve yield little water, while those which drop slowly are productive. The reason suggested why short rises do not contribute to diversions above the reservoir is that legal and physical conditions prevent adjustment of diversion intakes quickly enough to capture the rise before it has passed downstream.

The difference in the delivery of water to the San Carlos reservoir between the flash rises and the more enduring ones is due to the nature of the channel. From the head of the Duncan Valley to the head of the reservoir, the low-water channel now meanders through a wide gravelly bed bordered by a broad flood plain in which are dense growths of tamarisk, cottonwoods, and other water-consuming species. Over a period of years, the low and the high-water channels have deteriorated so greatly that, at present, high stages spread over extensive areas of permeable sands. Under summer conditions, evaporation from those areas is excessive; water stored in them is therefore lost into the atmosphere rather than converted into ground flow. Flash rises, being characterized by excessively high momentary peaks, do little more than saturate the bed of the high-water channel and so a great part of their volume is lost; the greater the volume of the short-period rise, the greater is the area of wetted surface, therefore, the channel loss is proportionally almost as great. More enduring river rises, on the other hand, wet proportionally smaller channel areas and so deliver to the reservoir far greater proportions of their volume.

The incidents in the Safford reach contain important implications for watershed management planning. A liberal estimate of the average annual discharge of the San Simon is 15,000 acre-feet. Samples taken for three years by the Soil Conservation Service indicate that at least 15% of the average discharge is sediment in suspension equivalent to about 2250 acre-feet. The observations here reported suggest that not over one-half of the San Simon discharge is delivered to the reservoir or diverted in the Safford reach; virtually all of the sediment in the San Simon flow, however, reaches the reservoir through the action of successive flows in the main channel. This means that 2250 acre-feet of silt are received for every 7500 acre-feet of water. The surface area of water stored in the reservoir is increased because of sediment accumulations, and, therefore, evaporation loss is increased. At a recent flood control public hearing, water loss from that and related causes was estimated as about 1/8 acre-foot per year for each acre-foot of sediment. This, in turn, means that the 2250 acre-feet of average annual San Simon silt delivery causes an annual evaporation loss of over 280 acre-feet of water; the 25-year accumulation of San Simon sediments (56,250 acre-feet) would cause an annual

evaporation equal to the 7500 acre-feet of effective water production.

These computations, being based on very conservatively selected, although meager, data demonstrate how hydrograph analysis may serve watershed planning: The above analysis indicates that, from the point of view of reservoir operator, the control of erosion on the San Simon watershed is warranted even though it involved a high consumptive use of water.

In connection with that point, the relation of sediments from areas like the San Simon to the regime of the river itself should also be considered. Heavy summer rains on such watersheds cause highly erosive floods along the tributaries which drain them. The flood crest is rapidly depleted after its entrance into the main channel with a resultant deposition of the erosion products it was transporting. These accumulate as bars which deflect the low flows, thus increasing meandering and causing increased channel losses and bank erosion by both winter and summer flows, as indicated in the preceding description of channel conditions. The only method for stabilizing the river channel which will be effective for a long period is to hold the sediments on the watershed lands. From the point of view of channel rehabilitation for water conservation and bank protection, therefore, management to withhold such sediments is necessary. This program should improve water supplies even though it involves an apparent consumptive use of water.

The third tentative conclusion previously mentioned is that a significant portion of those streamflow increments which materially contribute to irrigation supply is delivered to the river as ground flow. This is strongly suggested by analysis of observations 2, 3, 4, 7, 10, and 11. The way in which the hydrograph for the receding river approaches the base flow curve indicates ground water contributions, as has been shown by Horton, Hoyt and others (4,5). These increments from ground sources, of course, are not composed of the same particles of water which shortly before fell as rain. Since, however, the entry of that rain water into the ground system causes the release of groundwater into the river, that distinction is not of moment in this discussion.

While additional and more exact investigations are needed to supplement this preliminary one, the observations reported here clearly indicate that the relatively enduring or general summer rains are associated with ground water discharge increments, but that there is no such relationship with short-period or local precipitation.

The significance of this is brought out by an analysis of the relative frequency of the two types of storms. Precipitation records for 1936 and 1937 indicate that by far the greatest amount of summer precipitation occurs as general storms at a number of stations, or at fewer stations for several days. During May through October of those years, of the 1027 rains recorded at the 22 stations, only 123 were isolated storms which were not supported by other precipitation on the preceding or the following day. For the 10 stations at high and middle elevations, of the 572 recorded rains, only 49, or less than 9% were such isolated and unsupported storms. While the 1936 and 1937 records of summer precipitation are not necessarily completely representative of long-term records, it is the writers' belief that this relationship between isolated and more widespread summer precipitation holds in general for the upper Gila.

The points just discussed have a direct and important bearing on the design of watershed treatments. The short, local rains which cause so much erosion and river channel deterioration contribute little water to either the upper valleys or to the San Carlos reservoir. The use of this rain water in promoting an erosion-controlling vegetal cover, therefore, does not significantly detract from irrigation supplies, while it will improve the delivery from the more favorable type of storms.

The more enduring rains, on the other hand, not only are the principal source of summer water, but also, a large part of their contribution is made through ground channels. The latter is especially important since ground water increments make for long, slow river rises which, as have been shown above, are the only beneficial kind. These facts lead to a realization that watershed treatments which increase rainfall infiltration into ground-water channels will have a twofold beneficial effect on the summer water supply: they will decrease channel deterioration, and secondly, they will increase

the usefulness of river rises.

The types of treatments which will have that effect are of several kinds, applicable to the various situations. First in importance and an almost universal requirement, is the establishment of a grass cover. Grass keeps surface runoff from concentrating into surface streamflow, it checks the velocity of flow, and probably most important, grass roots maintain the porosity and infiltration capacity of the soil. In some areas, such as gravelly stream beds, grass must be partially replaced with shrub and tree vegetation because of growth conditions. In a few other areas, but in the upper Gila country only very rarely, gravel fans are good intake areas in the absence of any plant cover. With those few exceptions, for the reasons stated above, an adequate grass density on the watershed is of importance to the delivery of precipitation to the river.

Certain types of structures can materially supplement vegetation. Water-spreading dikes, brush or rock percolators, and similar devices directly promote infiltration by retarding the velocity and concentration of flow. Where there will be no interference with water rights, these often can be constructed in conjunction with diversion structures so as to convert torrential gully flows into sheet flow over intake areas.

In these paragraphs watershed treatment has been discussed from the point of view of improvement to the water supply. In laying out the program, consideration also must be given to erosion control and other objectives. In some cases the several objectives indicate different treatments; in most cases, however, the same measures with little or no modification serve several objectives. Grass, for example, and velocity checks concurrently increase infiltration and prevent erosion.

Again from the point of view of improving the water supply, introducing rain water into the ground is beneficial only if it will thus reach ground channels of flow. Infiltration should be increased only on the intake areas of the naturally established ground-water systems, otherwise evaporation from the soil would result in unproductive water loss. In the upper Gila country this directs the program largely toward the swales

and cienagas. These flats along the drainageways were formerly well vegetated and unchanneled; surface runoff from the surrounding slopes was checked there and introduced naturally into ground channels. Because most of these areas now are badly gullied and their vegetal cover is reduced in density, or is of kinds that do not effectively check runoff, their function with respect to ground water is largely removed. In addition, gravelly streambeds also are good intake areas.

This discussion indicated that the infiltration of runoff into the ground should be brought about principally in natural swales and that the treatment program should lead to the reestablishment of former conditions in them. This again serves the erosion control objective also. Objectives other than water supply improvement may of course justify runoff infiltration in other areas as well.

It might be well to point out that increased ground delivery of summer rainfall, or anything else which would lengthen the time-period of river rises would facilitate diversion above the reservoir. Even disregarding the decrease in channel loss (which would greatly benefit the reservoir users), it is probable that under the terms of the adjudication decree, the most effective use of water above the reservoir benefits both interests equally. This point, however, should be investigated further.

Conclusions

This study demonstrates that the analyses of existing streamflow and precipitation records can provide information needed for guiding the development of a treatment program for the upper Gila watershed. The authors recommend further and more detailed investigations which should include studies of the nature and significance of ground-water contributions to streamflow during the summer period.

Preliminary results indicate that short local summer rains do not contribute significant amounts of irrigation water. Longer or more general rains, which are the common type of summer storm, are the source of most of the summer water and much of their yield is delivered through ground channels.

Implications of this preliminary study are that vegetation and certain structural treatment developed so as to restore the former ground-water systems will improve the summer water supply. Such treatments also contribute to other objectives. Careful analysis of the various considerations bearing on each situation, however, is necessary.

References

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NOTE 1

Sample Calculation, Duncan Reach

This table illustrates how the values for observations 1-11, reported in Table 2, were computed from the daily means.

Calculations - Observation #1

Date*	Fuller's Ranch Gage			Valley Diversions			Clifton Bridge Gage		
	Flow	Depletion Curve	Increase	Flow	Trend Curve	Increase	Flow	Depletion Curve	Increase
June 10	23	23	0	38	38	0	17	19	
11	211	21	190	31	34	-3	17	19	
12	52	19	33	76	31	45	43	19	24
13	21	17	4	47	29	18	51	19	32
14	20	15	5	26	28	-2	29	19	10
15	20	14	6	29	27	2	27	19	8
16	20	13	7	29	26	3	25	19	6
17	19	13	6	29	25	4	22	19	3
18	17	13	4	27	25	2	21	19	2
19	15	12	3	24	24	0	19	19	
TOTALS			258			69			85

Total loss -- Fuller's Ranch increase minus the sum of the increase in diversions and increase in flow at the Clifton Bridge. Increase is that amount in excess of the depletion curve for that day.

Total loss -- 258 - (69 plus 85) = 258 - 154 = 104 Sec. ft. days.

*On June 5-9 and June 19 there was a normal river.

NOTE 2

Sample Calculation, Safford Reach

Increase in flow of Gila above mouth of San Simon	July 25-31,	400	Sec.	ft.	days
Increase in flow of San Simon Creek	July 25-31,	2065	"	"	"
Total Increase		2465	"	"	"
Increase in diversions below mouth of San Simon	July 25-31,	388	"	"	"
Increase in flow of Gila at Calva	July 25-31,	870	"	"	"
Total Increase		1258	"	"	"
Difference Is Net Loss of		1207	"	"	"

This computation assumes no contribution below mouth of the San Simon.